A 4-MJ MOBILE PULSE POWER FACILITY FOR ELECTROTHERMAL-CHEMICAL GUN RESEARCH

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ABSTRACT

In support of advanced electric gun research in progress within the U.S. Army, a mobile pulsed power system has been developed and made operational as part of the Army Research Laboratory (ARL) electric gun research facility. This mobile system has a maximum energy storage capability of 4 MJ, and it can deliver gigawatt levels of pulsed power over time periods of several milliseconds. The configuration of the system is that of a pulse-forming network (PFN) that is comprised of a bank of 80 high-energy capacitors, pulse-shaping inductors, switches and other electronic components which are designed to provide a variety of pulsed power profiles for electric propulsion research. The prime power for the PFN consists of a 1-MW diesel generator interconnected with a 27-kV constant voltage power supply. The system is controlled and monitored with electronic instrumentation from a remote control station which makes use of optical fiber signal transmission techniques. Recently acquired experimental pulsed power data from the facility are presented and discussed.

BACKGROUND and EXPERIMENTAL

Pulse-Forming Network Characteristics:

The pulse-forming network (PFN) design for this electric gun facility was selected mainly on pulsed output-power versatility. As a result, a type C network was selected, which consists of multiple inductor-capacitor (LC) circuits or submodules, each having its own output closing switch. This configuration is considered a "voltage-fed" network, which stores energy initially in the form of an electrostatic field on capacitor plates. The electrical energy is released in the form of output current flow to a load impedance[1]. The main power components used in the system include capacitors, inductors, rectifiers, and high-power switches, which are shown schematically in the diagram, Figure 1. Versatile pulse shaping is obtained by adjustments in the temporal delay of the output switches. This feature has been demonstrated both experimentally and through the use of electronic circuit simulations for this particular power system, and it is discussed further in this paper.

Initial work on the PFN design was performed by Maxwell Laboratories Inc., San Diego, CA, with technical input and requirements provided by the U.S. Army, the details of which have been published elsewhere[2-3]. PFN design, systems validation, testing, and technical consultation were also performed by Vitronics Inc., Eatontown, NJ, through contract No. DAAL01-92-C-0265 during the period of March 1993 through April 1995. The completed pulsed power supply consists of ten PFN submodules and a total of 80, 50 kJ, type C, energy storage capacitors (Maxwell model 32511). Each capacitor has an energy density of 0.66 J/g, maximum charging voltage of 24 kV, and internal capacitance of 175 μF.

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Other power components include pulse-shaping inductors, high-power rectifiers, and spark gap closing switches. The system operates as two separate modulators each with 40 of the previously mentioned capacitors. Each modulator contains five banks of eight parallel connected capacitors, which together store a total of 2 MJ of electrical energy. The stored energy is delivered from all submodules to a common output load, e.g., an electric gun. Each of the ten submodules is directly connected to a pulse-shaping inductor and output spark gap closing switch. Power rectifiers at the end of each submodule line are used for capacitor voltage reversal protection, and they effectively extend the life expectancy of the PFN capacitors by shunting the capacitors during voltage reversal. The feature of ten independently triggerable submodules with adjustable time delay provides the pulsed output versatility required for several electric gun research programs of interest to the U.S. Army. Experimental and simulated PFN output profiles for a 2- MJ PFN modulator are shown in the data plots of Figures 2 through 5.

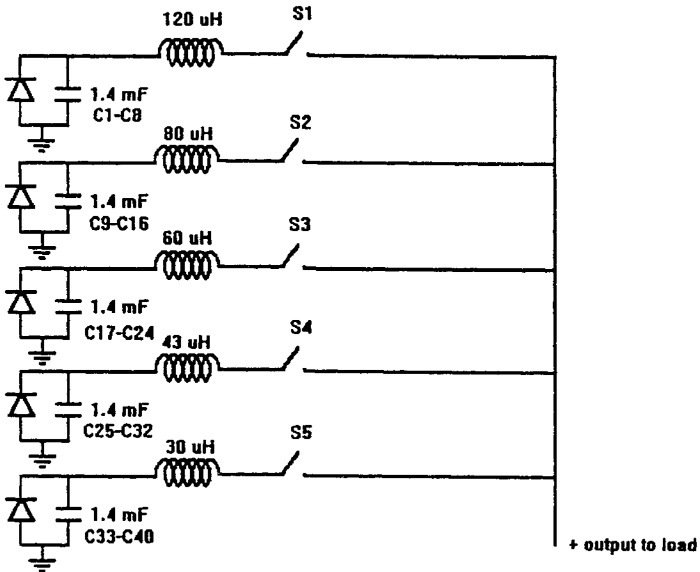
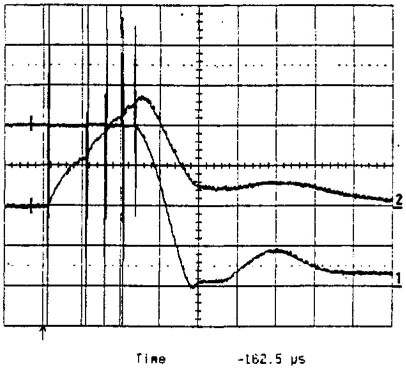
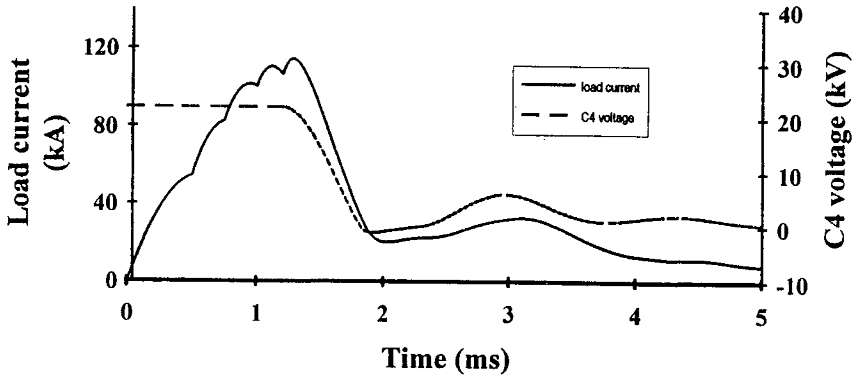


Figure 1. Circuit diagram of a 2-MJ pulse forming network in the ARL mobile pulser system used for electric gun research.

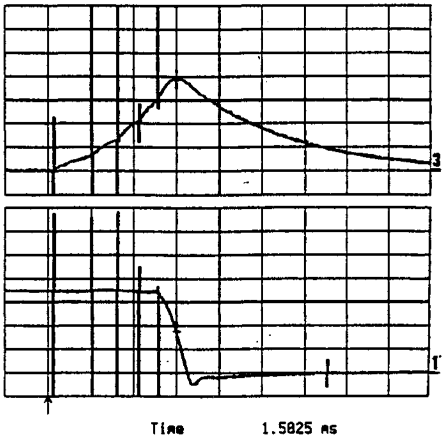
The PFN pulse-shaping inductors are manufactured by Trench Electric, and individual units range from 30 to 120 μH of inductance. Each inductor is electrically tested before insertion in the power supply to an electric potential of 132 kV. This procedure ensures proper pulsed power operation once the inductor is installed and exercised in an experimental program. International Rectifiers, Marcum Onterio, Canada, produces the power rectifiers used in the PFN, which are model No. C03-1488.

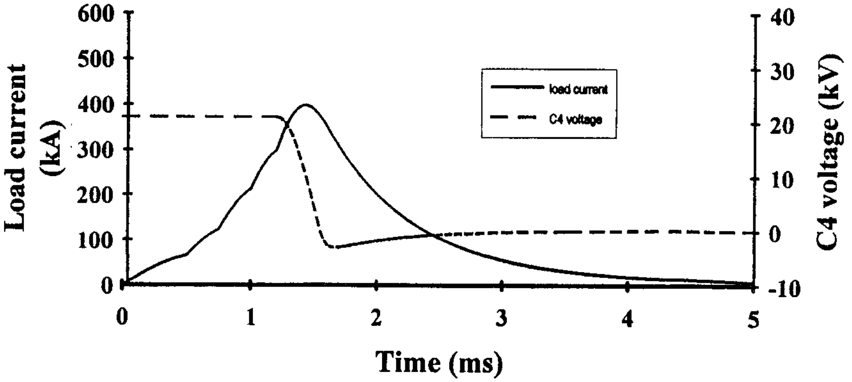




(a) (b)

Figure 2. Experimental (a) and simulated (b) output load current and C25-32 voltage from cap bank four the 2-MJ PFN submodule. Both data plots are with a 120-mΩ load resistor and an initial capacitor voltage of 22 kV. Closing switch times are set at 0, 0.5, 0.75, 1.0, and 1.2 ms.





(a) (b)

Figure 3. Experimental (a) and simulated (b) output load current and C25-32 voltage from the 2-MJ submodule during fault analysis. The load resistance for the PFN is a short circuit (4.2-mΩ load). Intital capacitor voltage is 21 kV and switch closing times are 0, 0.5, 0.75, 1.0, and 1.2 ms.

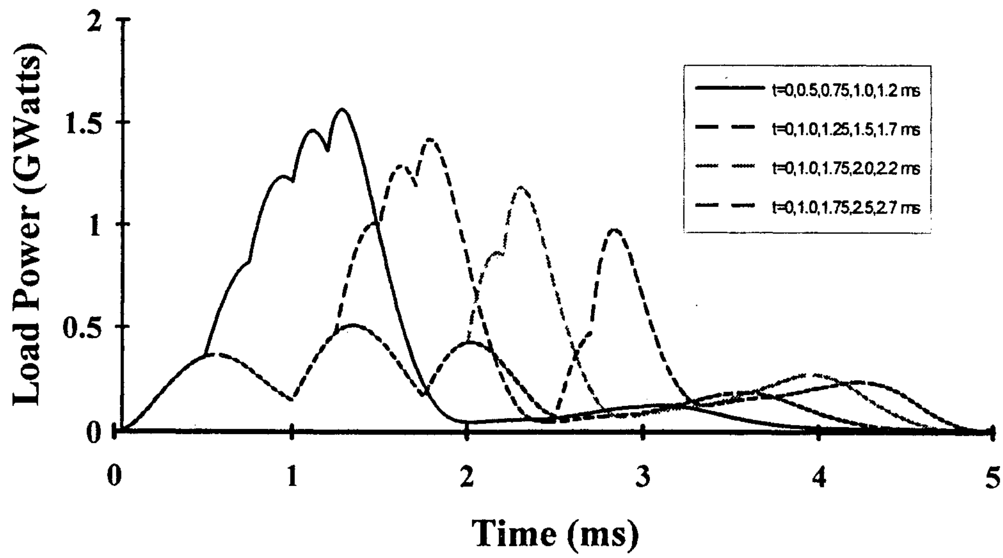


Figure 4. Demonstration of versatile output power waveforms through circuit simulations of a 2-MJ modulator into a 120-mΩ load having varied closing switch times. The closing times for the switches are indicated by the plot legend.

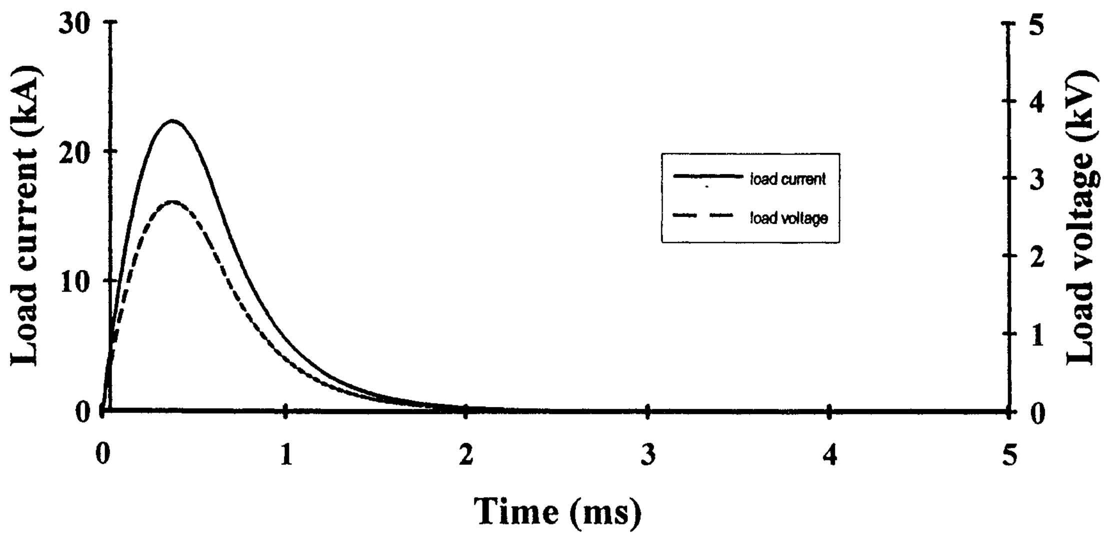


Figure 5. Simulated output current and voltage from one capacitor bank (bank three with 60-μH series inductance) of a 2-MJ modulator into a 120-mΩ load showing a pulse period of 1 ms.

The main function of the rectifiers is capacitor voltage reversal protection. The rectifiers are high-power silicon pn diodes having a reverse breakdown voltage rating of 15 kV and maximum forward current rating of 60 kA (8-ms pulse duration). Closing switches are manufactured by Physics International, CA, and are rated for 280 kA of peak pulsed current. The trigger generator that drives the spak gap and begins the main current flow from the PFN is the Physics International model TG-75.

Control System:

The control system provides remote operator control and monitoring functions for the 4-MJ pulser and prime power generators. The system was designed and fabricated by Vitronics, Inc. Eatontown, NJ under contract No. DAAL01-92-C-0265 managed by the U.S. Army Research Laboratory (ARL). As with the PFN design, system requirements for the 4-MJ control system were produced jointly by the Physical Sciences Directorate (formerly Electronics and Power Sources) and the Weapons Technology Directorate of the ARL. The main components of the control system are the trigger generator power supply or signal generator, capacitor charging control system, sequence-fault system, remote control, and power supply hardware.

The control system consists of an Interface Technology model RS-670 40-MHz digital signal generator, digital voltmeter displays for capacitor voltages, high voltage power supply control circuits, spark gap switch trigger generators, safety relay control functions, and emergency circuits for experimental abort situations. The RS-670 signal generator provides trigger signals which are converted to optical signals and transmitted to the PFN spark gap switches. The word generator has a maximum of 64 output channels and is capable of operating at data rates as great as 40 MHz with time variant digital output. The generator features a menu driven format in which operator interface is provided through a CRT. Remote programming of the generator is possible through an optional IEEE-488 and RS-232 ports.

The capacitor charge system makes use of voltage-to-frequency converters and fiber optic signal transmission for voltage monitoring of the PFN capacitors. Hewlett Packard model HFBR-1402 optical transmitters and ADVF32KN voltage to frequency converters are the main components used in capacitor voltage to frequency converter circuits.

The system controller, see Figure 6, with hardware as mentioned is arranged in a standard 19 inch equipment rack that is interconnected to the PFN through multimode fiber-optic cables. Color video cameras and monitors are an integral part of the control system and were included to aid in confirming system safety status. The video cameras also are used for diagnostic purposes in the event of a component or system failure during an electrical discharge event.

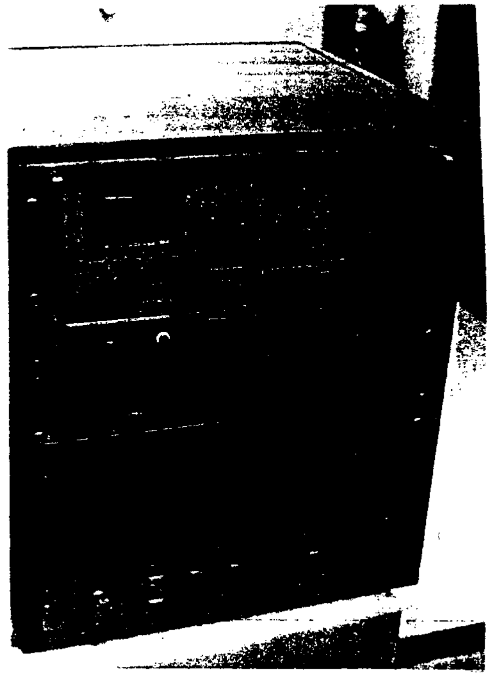


Figure 6. Control system for the 4-MJ mobile pulser system.

SUMMARY

A 4-MJ mobile pulsed power system has been designed, fabricated, and tested under the technical and managerial supervision of the U.S. Army Research Laboratory for the purpose of electric gun propulsion research. Demonstration tests documented in this report have shown the system to be versatile in terms of output power pulse shaping, which is due to the multi-PFN and switch aspect of the power system. High energy capacitors, pulse-shaping inductors, and high voltage rectifiers are essential power components that have been incorporated into the PFN, which is controlled by a remote control system based on an Interface Technology digital signal generator and fiber-optic interconnections.

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